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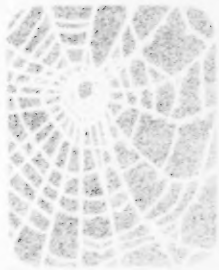

Spider
Engineering

TITLE: PROTOTYPE

HIGH EFFICIENCY

FURNACE DEVELOPMENT

Final Report
By

SPIDER ENGINEERING ASSOCIATES (WATERLOO) INC.

J.L. Wright
R.J. Briggs
H.F. Sullivan

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SUMMARY

The following report summarizes a project which was undertaken in order to develop and test prototype, high efficiency, condensing, gas furnaces. This project was conducted for The Consumers' Gas Co. and the Department of Energy, Mines and Resources.

This research and development was undertaken in order to prove the operation and refine the design of a condensing gas furnace which utilizes a unique patentable recirculation loop. This recirculation loop cools the flue gas sufficiently to allow the use of plastic as a condensing heat exchanger material. Coroplast, a polyethylene/polypropylene copolymer extrusion, has been used for the construction of the condensing heat exchangers which were used to construct the prototype furnaces.

The furnace development required successive design, construction and design refinement steps during the development of the current prototype model. This prototype furnace has been tested for reliability, safety and thermal performance. The prototype furnace has a steady state efficiency of 92%. The seasonal efficiency is not expected to differ significantly from the steady state efficiency.

The recirculation loop is capable of cooling flue gas (which is to enter the plastic heat exchanger) to below 95C. The furnace controls and safety system are expected to be sufficiently complete and reliable enough to prevent any health hazard or damage to the furnace resulting from a component malfunction.

Coroplast appears well suited for use as a heat exchanger material in this application. The thermal performance is acceptable and the corrosion resistance of the plastic is very good. Various experiments have been completed in order to test the plastic for thermal and chemical degradation as well as permeability. There was no evidence of plastic degradation in these tests or under normal furnace operation.

It is recommended that further research be conducted into the economical manufacture and sealing of the Coroplast heat exchanger. This work, combined with modifications of the recirculation and exhaust blower configuration, would result in a furnace design worthy of serious consideration for manufacture and marketing.

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CHAPTER 1

INTRODUCTION

A project to develop and test prototype, high efficiency, condensing, gas furnaces was undertaken by Spider Engineering Associates under contract to The Consumers' Gas Co. and The Department of Energy, Mines and Resources. This project is a continuation of work performed by Spider Engineering (1), as part of which a conceptual design of a high efficiency residential gas furnace was developed. This design utilizes a unique flue gas recirculation process which enables the use of a low temperature plastic heat exchanger to cool the combustion products into the condensing temperature regime. The use of a plastic material in the condensing portion of the heat exchanger provides a resistance to corrosion that is superior to that typical of metals.

The objectives of the current work were twofold. The first objective was to design and construct functional prototypes of the proposed conceptual furnace design. Thus, the proof of concept, with respect to the unique features of the process, would be provided. In addition, practical experience regarding the various aspects of the furnace construction could be gained. The second objective of the project was to test the plastics used in the furnace condensing heat exchanger for degradation. A review of plastics testing standards was made, and various tests were designed and performed. These experiments tested for thermal and chemical degradation as well as permeability. The prototype development required successive design refinement steps to arrive at the finalized prototype. These prototype furnaces were then tested for thermal performance, reliability and safety.

CHAPTER 2

FURNACE DESIGN AND OPERATION

2.1) FURNACE OPERATION

2.1.1) Conceptual Furnace Process

The conceptual process which takes in the prototype furnaces is shown in Figure 1. The following paragraph describes the general operation of this process.

Room air and natural gas are burned in the lower section of the primary heat exchanger to produce combustion products (flue gas). The flue gases pass through a duct to a secondary, condensing heat exchanger where they are cooled to approximately 38C. A portion of this flue gas flow which exits the condensing heat exchanger is recirculated to mix with, and cool, the flue gas which flows from the primary heat exchanger to the condensing heat exchanger. This tempering process allows the use of plastic as a condensing heat exchanger material. The remainder of the cooled flue gas exiting the condensing heat exchanger is exhausted.

2.1.2) Sequence of Operation

The sequence of events typical of the operation of the prototype furnace will be described by following the furnace through a start up and shut down cycle. The completed prototype furnace is shown in Figure 2. References will be made to the parts diagrams, Figures 3, 4 and 5, by noting the part number immediately after the component name; eg. exhaust blower (PN 14). The plastic heat exchanger is fabricated from Coroplast (a polyethylene/polypropylene copolymer extrusion) and is detailed in Figures 6,7 and 8. The furnace wiring diagram is illustrated in Figure 9.

A demand for heat from the thermostat will first start the recirculation blower (PN 13). The exit of this blower has a sail switch (PN 21) designed to prove recirculation blower operation. The flow from the recirculation blower will close the sail switch, thereby completing the circuit for exhaust blower (PN 14) operation.

Operation of the exhaust blower is monitored by the pressure switches (PN 11, PN 12). With both the recirculation and exhaust blowers operating, these pressure switches provide power to the burner circuit. This initiates a heater relay switch (part number 10 of Figure 9). The contacts of this switch close approximately 15 seconds after electrical voltage is applied to the switch heater element. This ensures a fifteen second

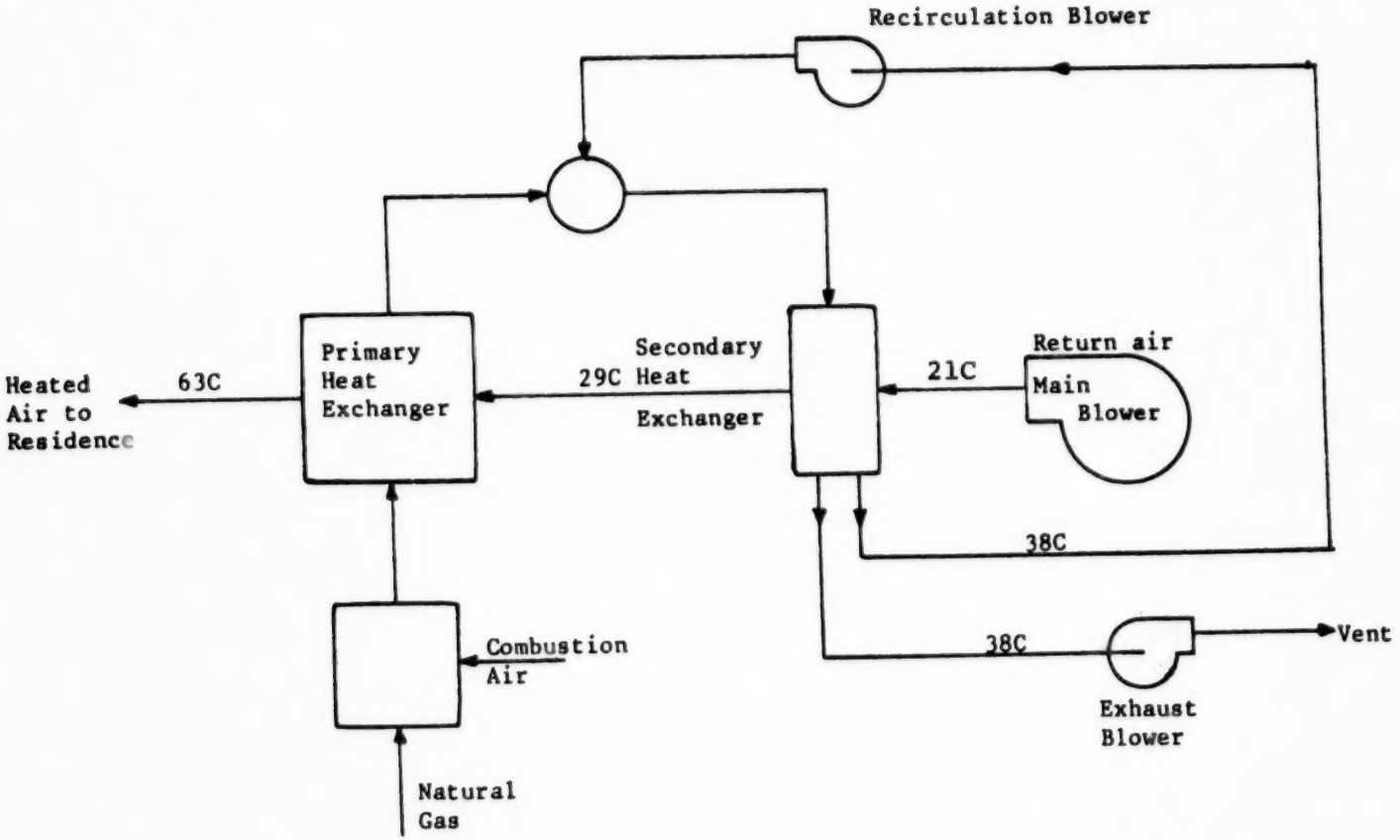


Figure 1 Recirculation Furnace Process Schematic

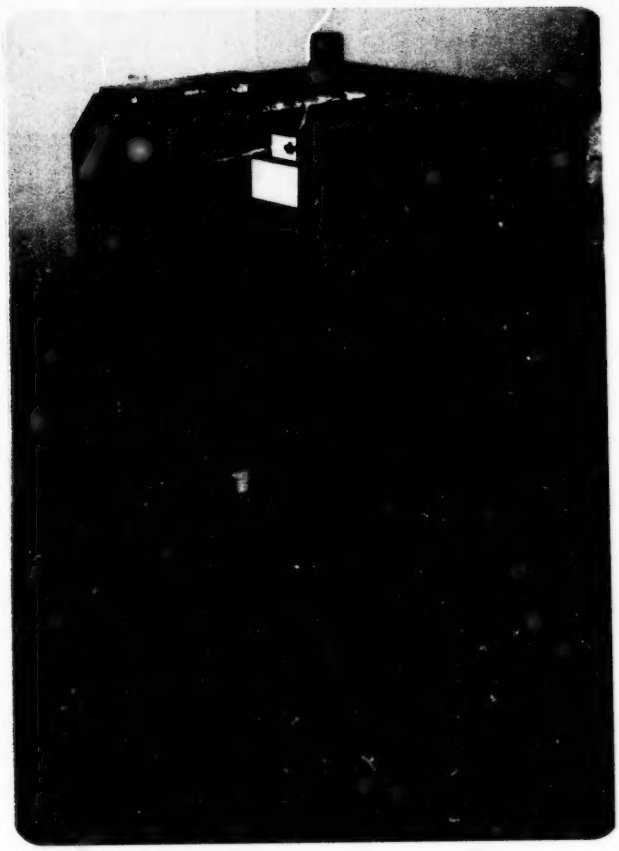
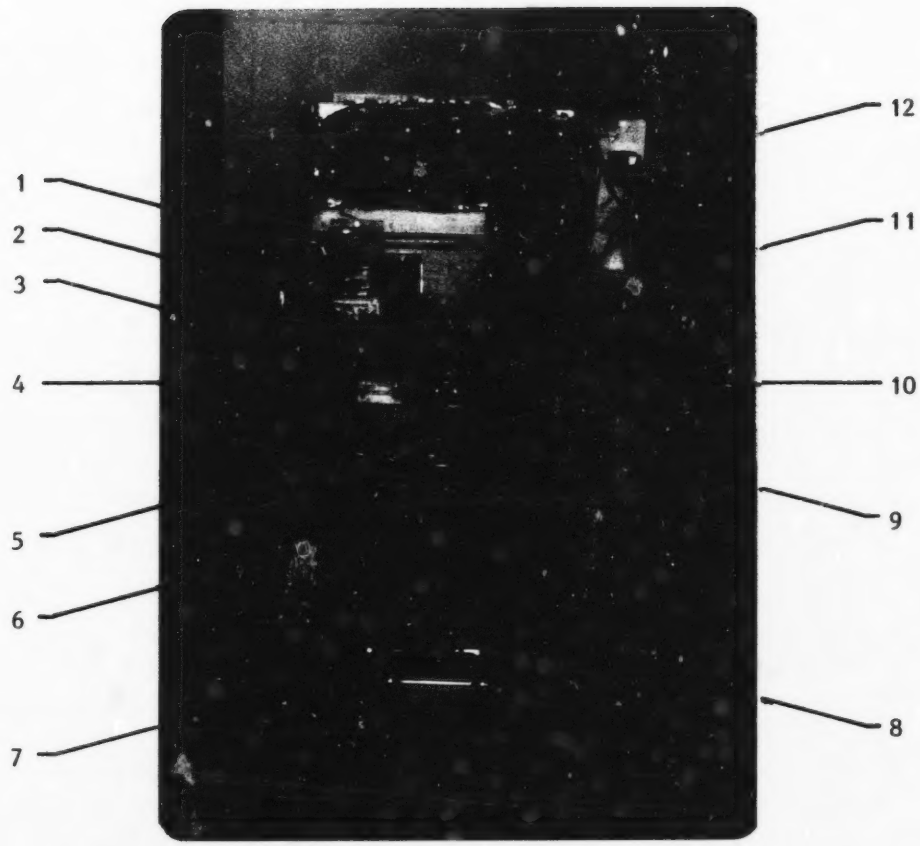
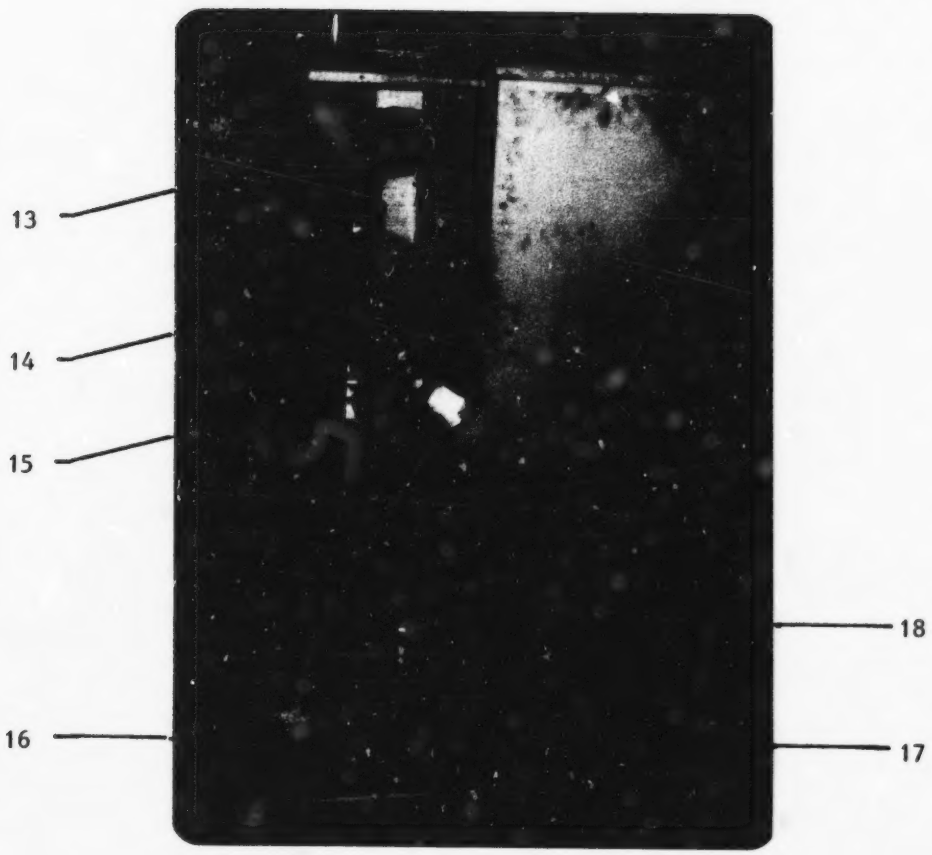


Figure 2 : Prototype High Efficiency Condensing Furnace



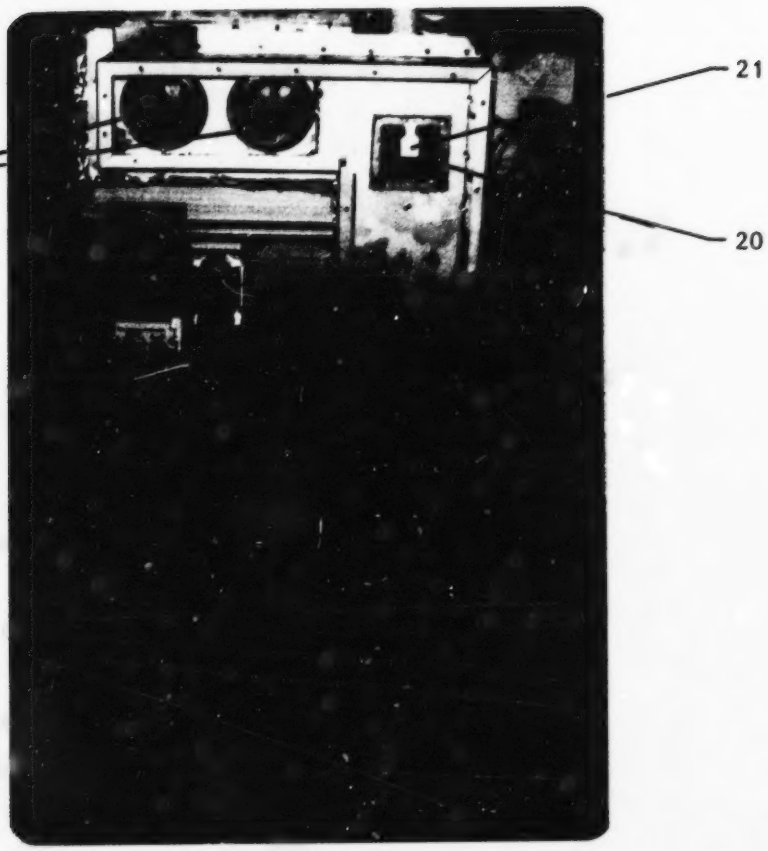
1 Fan Control Temperature Sensor
2 Electronic Ignition and Control Wiring
3 Gas Regulator
4 Spill Switch
5 Burners
6 Inlet Manifold; Condensing Heat Exchanger
7 Main Blower Assembly
8 Condensate Treatment System
9 Temperature Sensor; Recirculation Duct
10 Recirculation Duct
11 Pressure Switch (Low)
12 Pressure Switch (High)

Figure 3 : Prototype Furnace Parts Diagram ; Front



13 Recirculation Blower
14 Exhaust Blower
15 Exhaust Vent Pipe
16 Condensate Overflow Hose
17 Condensate Drain Hose
18 Outlet Manifold; Condensing Heat Exchanger

Figure 4 : Prototype Furnace Parts Diagram ; Rear



19 Primary Heat Exchanger Exhaust Outlet Ports
20 Recirculation Blower Exit Port
21 Sail Switch Flag

Figure 5: Prototype Furnace Parts Diagram; Upper Front

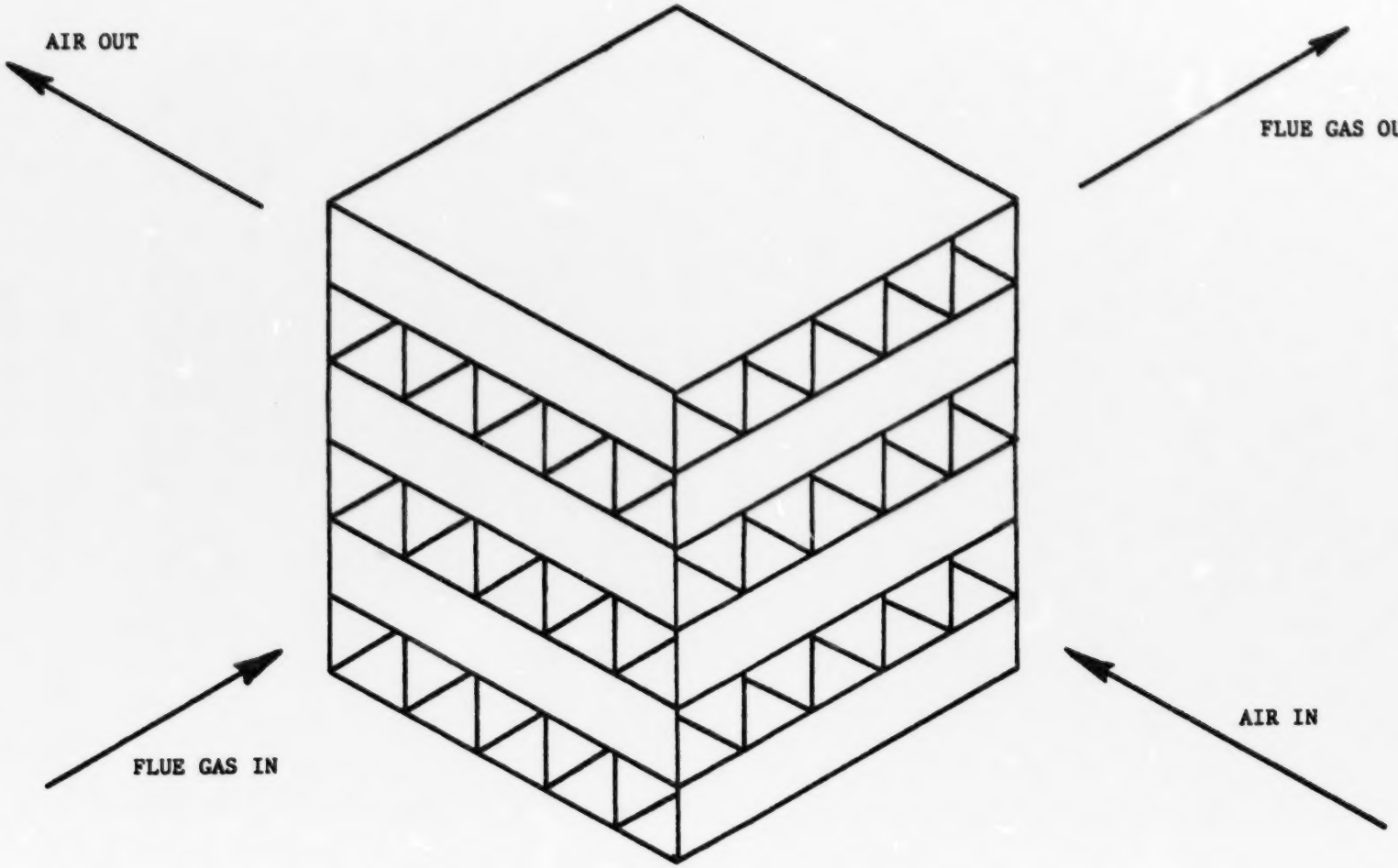


Figure 6 : Construction of a Six Sheet Coroplast Heat Exchanger

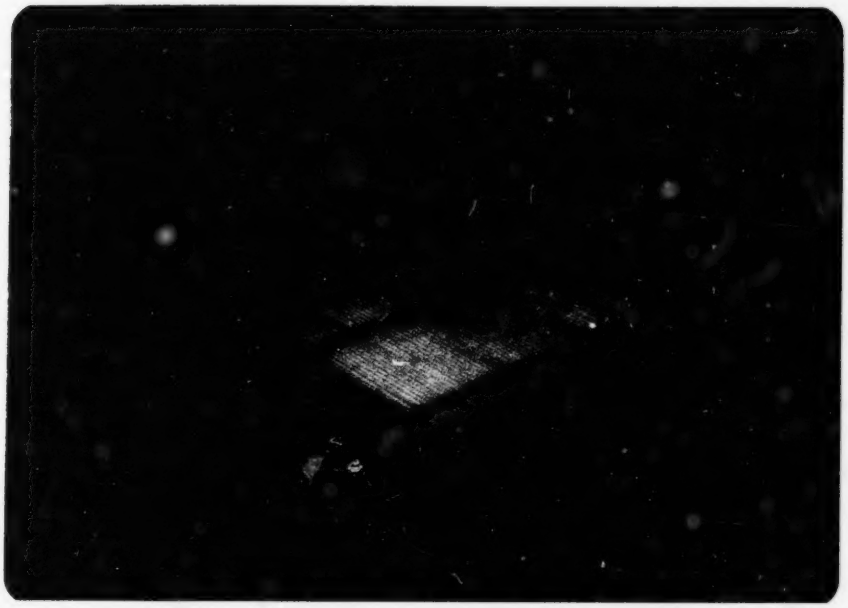
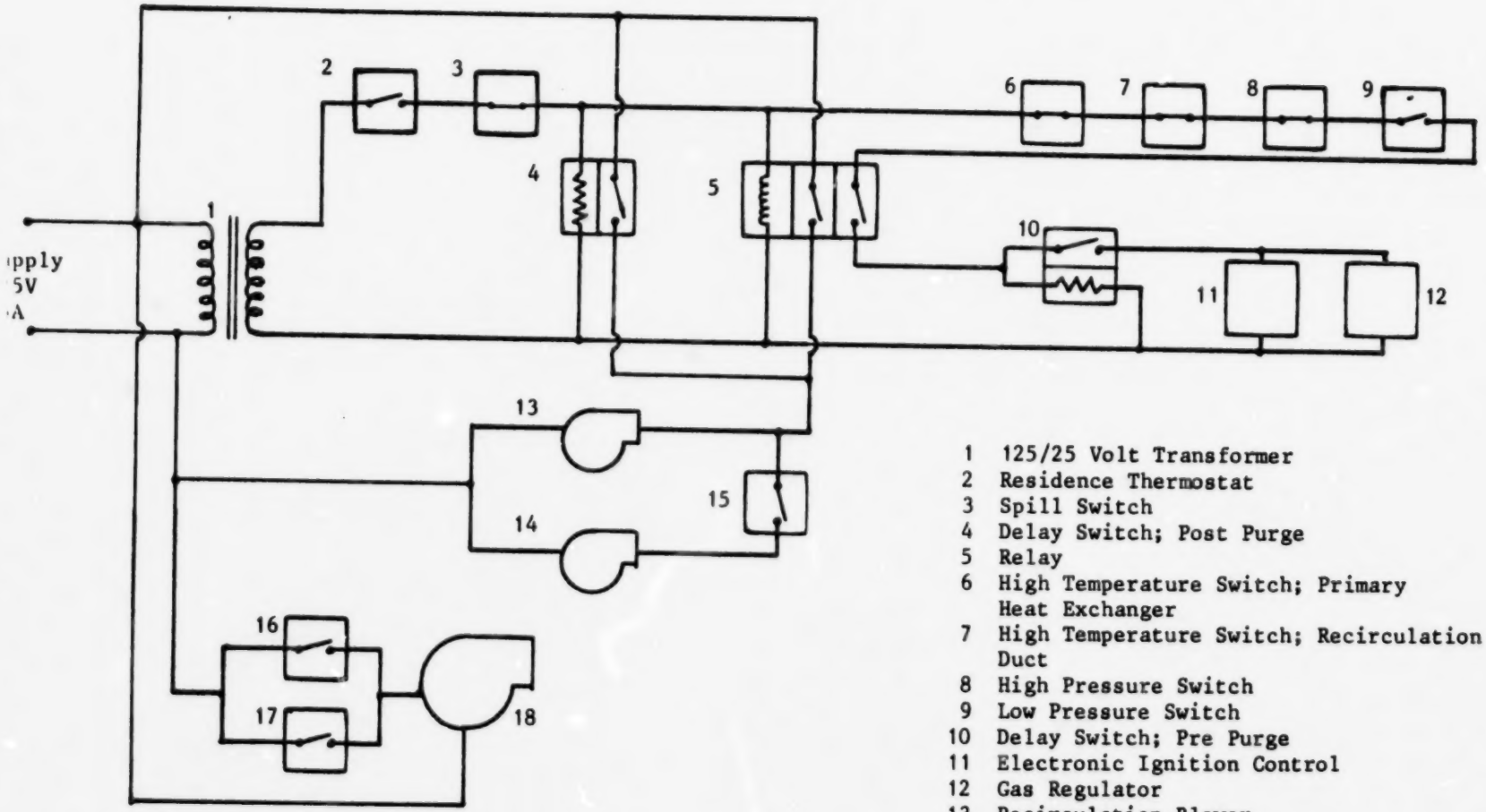


Figure 7: Coroplast Condensing Heat Exchanger

Figure 8 : Condensing Heat Exchanger as Installed

Inlet manifold showing.



1 125/25 Volt Transformer
2 Residence Thermostat
3 Spill Switch
4 Delay Switch; Post Purge
5 Relay
6 High Temperature Switch; Primary Heat Exchanger
7 High Temperature Switch; Recirculation Duct
8 High Pressure Switch
9 Low Pressure Switch
10 Delay Switch; Pre Purge
11 Electronic Ignition Control
12 Gas Regulator
13 Recirculation Blower
14 Exhaust Blower
15 Sail Switch
16 Temperature Switch; Primary Heat Exchanger
17 Temperature Switch; Recirculation Duct
18 Main Blower

Figure 9 : Furnace Wiring Diagram

delay before the pilot flame is ignited which allows a pre-purge of the primary and condensing heat exchangers.

Once the heater relay switch has activated the remainder of the burner circuit, the pilot flame is established by an electronic ignition unit (PN 2). A temperature sensor near the pilot flame proves ignition and allows the main regulator (PN 3) to open and ignite the main burners. With the burners lit, the flue gas is circulated through the primary and to the condensing heat exchanger. The flow from the condensing heat exchanger outlet header (PN 18) is divided into two streams; one is exhausted and the second is recirculated. Thus, the flue gas from the primary heat exchanger is continually tempered by recirculated gases. Both of the temperature controls (PN 1, PN 9) have a lcw temperature set point. If either the temperature of the flue gas entering the condensing heat exchanger or the temperature of the air at the primary heat exchanger reaches its respective set point, the main air blower (PN 7) will start and warm air will be circulated to the conditioned space.

Upon satisfaction of the space heating requirement, the thermostat opens the circuit causing the burners to be shut off. The exhaust and recirculation blowers remain operating for a fifteen second post-purge of the furnace. This post-purge is controlled in a manner similar to that of the control of the pre-purge operation. The main air blower remains running until both temperature controls (PN 1, PN 9) have cooled below their lower set points.

2.2) SAFETY SYSTEMS AND INTERLOCKS

The furnace has various interlocks to prevent startup if problems should arise, as well as safety systems which monitor furnace operation continually. Both the interlock and safety controls serve essentially the same purpose, namely, protection against malfunction. This section discusses how the various control devices function in the system and the control hierarchy.

The interlock-safety system checks for two conditions continually; acceptable temperature levels and proper blower operation. The purpose of the protection system is to ensure that the furnace neither damages the plastic heat exhcanger nor creates a health hazard for the dwelling occupants.

Protection against overheating is provided by two temperature controls (PN 1, PN 9). These controls have an upper set point which will interupt the burner operation and thus prevent damage. The temperature control located at the flue gas inlet to the plastic heat exchanger has a high set point of 110C.

The temperature control located on the air side of the primary heat exchanger has an upper limit of 82C. Should either of these temperature controls rise above its respective high set point the burners will be stopped until the furnace has cooled sufficiently to reoperate. The shut down of the burners is followed by a flue gas post-purge.

The flow proving devices on the furnace consist of a sail switch (PN 21) and two pressure switches (PN 11, PN 12). These devices ensure recirculation and exhaust flows prior to and during burner operation.

The low and high pressure switches are connected to a pressure tap located immediately downstream of the flue gas exhaust blower (PN 14). The purpose of these pressure switches is to ensure an acceptable amount of flue gas exhaust flow. The burner circuit will not be complete unless the exhaust blower exit pressure is within the low to high pressure control range. If the measured pressure is less than the amount required to close the low pressure switch (PN 11) then the furnace is not operating with sufficient excess air for safe operation and the burners will not ignite. If the exhaust flow is restricted, the measured pressure will rise above the high pressure cut off and burner operation will be terminated. This condition might correspond to a blocked exhaust pipe.

The recirculation blower (PN 13) utilizes a sail switch (PN 21) to ensure recirculation flue gas flow. This sail switch controls the power to the exhaust blower (PN 14). Hence, if the recirculation blower fails to operate, the exhaust blower supply circuit is interrupted. This in turn will cause the low pressure sensing switch (PN 11) to interrupt the burner operation and to shut down the furnace.

As a protection against exhaust blower malfunction and a potential carbon monoxide health hazard, a spill switch has been installed near the burner opening at the entrance to the primary heat exchanger. If for any reason the flow of exhaust gas should reverse, the hot gases will trip the (93C limit) spill switch and interrupt burner operation. This switch must be manually reset. This requirement ensures that the the furnace receives attention and is serviced prior to restarting.

2.3) DESIGN MODIFICATIONS

The development and construction of the prototype furnaces was based on the theoretical work detailed in references 1 and 2. The original design and procedures proposed in these documents were modified as the development progressed. The following section outlines the modifications that were made and the reasoning behind these design changes.

The original plan called for modifications to be made to the primary heat exchanger in order to reduce the exhaust temperature of the flue gas to approximately 500F. These modifications included the use of flow diverters and black radiation curtains in order to enhance the flue gas to air heat transfer coefficient. The initial work to modify the primary heat exchanger in order to achieve lower flue gas exit temperatures met with only marginal success. At this point the decision was made to leave the primary heat exchanger design unchanged, and increase the flow of recirculation gases slightly in order to achieve the required gas temperatures at the inlet of the plastic heat exchanger. It is expected that the unmodified primary heat exchanger will be reliable since this design has been utilized in conventional gas furnaces for many years.

The proposed prototype design included combustion air preheat, to which could be attributed an extra one to two percent efficiency. The combustion air preheat was dropped from the prototype design in order to avoid complications in the construction and sealing of the plastic heat exchanger.

The proposed plan of work for this research project detailed a research plan which included investigation of possible flow channelling on the air side or exhaust side of the Coroplast heat exchanger. This investigation revealed that channelling ocurrs to some degree on both sides of the condensing heat exchanger. Due to space limitations, the Coroplast heat exchanger is located within several inches of the main air blower outlet. As a result, the air flow is greatest through the portion of the heat exchanger which is directly adjacent the air blower discharge. However, this channelling was not deemed to be of a serious enough nature to necessitate design modifications.

The flue gas side of the condensing heat exchanger has two exit ports on the outlet header. These ports are seperated by a divider panel. The function of this divider is described in a subsequent section. The temperatures of the two flue gas streams leaving the plastic heat exchanger may differ by as much as 6C indicating the possible presence of flue gas channelling. However, overall furnace performance is satisfactory despite the limited degree of channelling that does exist in the condensing heat exchanger. Elimination of the channelling that does exists would not be expected to greatly enhance the overall furnace performance.

CHAPTER 3

PERFORMANCE CHARACTERISTICS

The performance characteristics of the prototype furnace were measured over the full range of possible operating conditions. This section discusses the steady state temperature levels and the parameters which affect the operating temperatures of the furnace. The pressure profile throuthout the recirculation loop is examined and thermal performance data presented.

The steady state temperature levels throughout the furnace are dictated by the amount of excess air provided for combustion. This, in turn, is governed by the amount of exhaust flow, or exhaust tube back pressure, which is allowed. The exhaust blower and recirculation blower both draw flue gas from the exit of the plastic heat exchanger (See Figure 1). Hence, there is an interaction between the flow rates of these two blowers.

To understand the exhaust/recirculation relationship consider the following. The exhaust tubing connected to the furnace outlet can vary in length from one installation to another. If the exhaust vent pipe were long, the exhaust back pressure would be high and relatively little excess air would be moved through the furnace. As a result, the amount of recirculation flow increases and the temperature of the flue gas entering the plastic heat exchanger drops. The converse is also true. If the exhaust pipe were very short, the exhaust flow would increase and the recirculation flow would decrease (Excess air would increase). Thus, the temperature of the flue gas entering the plastic heat exchanger would increase. The back pressure on the exhaust blower is thus of vital importance to the proper furnace operation. This discussion is illustrated in Figure 9 which shows typical temperature levels versus excess air.

The furnace operating range is limited by two constraints. The excess air must not decrease below 30%, as the combustion products may spill from the mouth of the burner compartment if the excess air approaches 0% (Stoichiometric air). This constraint is ensured via the high pressure switch which senses exhaust blower back pressure. The other end of the operating range is constrained by the inlet temperature to the plastic heat exchanger. This temperature must not exceed 110C and is monitored by a temperature control (PN 9). Thus, in the case of the prototype furnaces being discussed here, the upper limit of acceptable combustion air flow is approximately 75% excess air.

It is readily apparent from the above discussion that the exhaust/recirculation flow relationship is the controlling

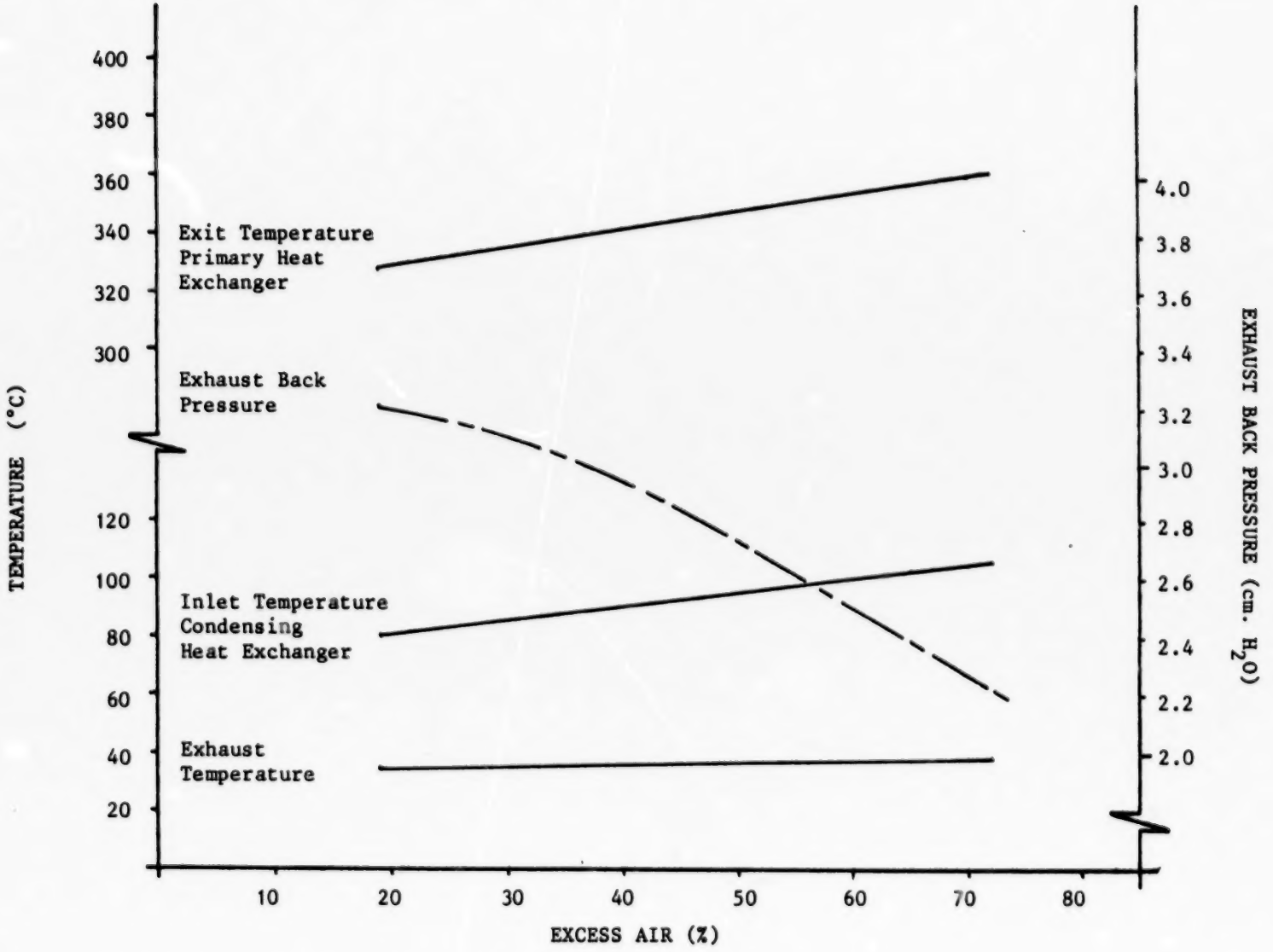


Figure 10: Typical Furnace Performance Curves

factor in furnace operating temperature levels. The purpose of the dividing panel in the Coroplast heat exchanger exhaust manifold is to reduce or minimize the degree of interaction between the two (exhaust and recirculation) blowers. The dividing panel reduces the sensitivity of interaction between these blowers, and thus the sensitivity of the plastic heat exchanger inlet temperature to exhaust back pressure is reduced.

The thermal performance of the furnace was determined according to the exhaust temperature, amount of excess air and quantity of condensate produced. The steady state efficiency was found to be approximately 92% (76.5 kBTU/hr firing rate, 23C ambient temperature, 39C exhaust temperature, 25% excess air, 1592 gm/hr condensate produced). It is of interest to note that less condensate was produced than might have been expected in light of the measured exhaust temperature and excess air levels. This, presumeably is a result of small amounts of air which were able to leak into the flue gas stream and suppress the dew point temperature. It is not expected that the seasonal efficiency will differ appreciably from the steady state efficiency.

The temperature transients typical throughout a start up and shut down cycle are shown in Figure 11.

Regardless of the amount of excess air with which the furnace operates the pressure levels at the various points along the flue gas path are similar. These pressure levels dictate the direction and quantity of flue gas flow. As the prototype furnace uses a unique recirculation loop, the pressure levels throughout this loop are of interest. The pressure must decrease through the primary heat exchanger from atmospheric pressure at burner inlet to some value marginally below atmospheric at the primary heat exchanger outlet. The combined flow of exhaust gas and recirculated gas enters the Coroplast heat exchanger and exits to the outlet header. The pressure in the condensing heat exchanger outlet header is the lowest pressure in the system. At this point the exhaust blower boosts pressure above ambient to discharge and the recirculation blower increases the pressure of the flue gas to that level necessary for recirculation. Thus, the flue gas pressure is less than atmospheric throughout the entire recirculation loop up to the exhaust blower. The exhaust blower outlet is connected to the exhaust vent by 2½" diameter PVC pipe (PN 15) which is presumed leakproof. Thus, with the exception of the exhaust outlet port, the flue gas in the recirculation loop is at lower than ambient pressure. The furnace was constructed in such a way that the closed cabinet is pressurized by the main air blower. This reduces the risk of delivery air contamination by flue gas.

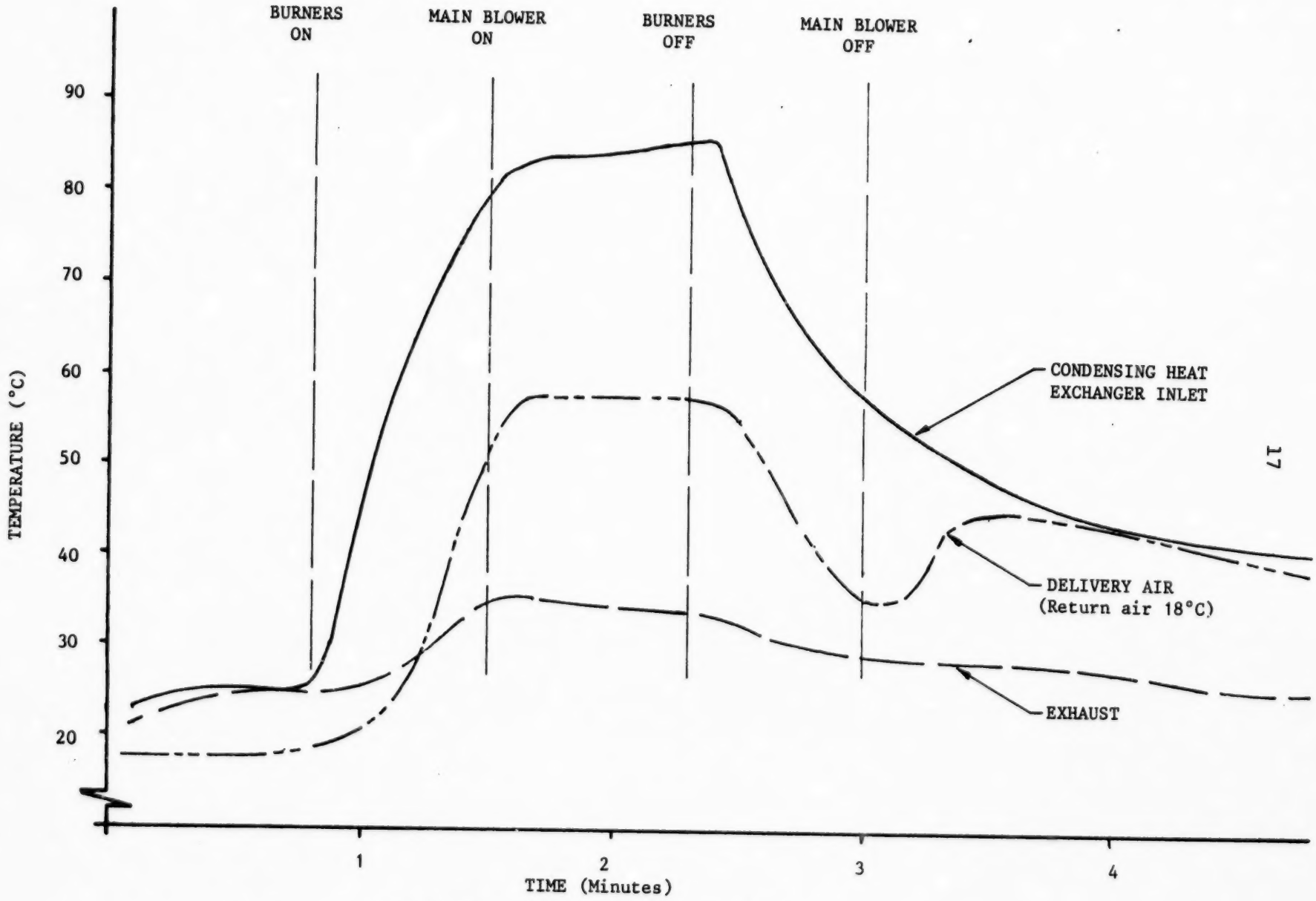


Figure 11: Transient Temperature Profiles

CHAPTER 4

PLASTICS ASSESSMENT

4.1) APPROACH

The prototype condensing furnace developed during this project utilizes a unique recirculation loop to cool exhaust gases prior to entering the plastic heat exchanger. The application of low temperature plastics (specifically Coroplast) as a condensing heat exchanger material in a residential furnace has not been investigated before. Therefore, research and testing of materials performance was an important part of the study. In a condensing furnace for residential heating, the three areas of vital importance in materials assessment are:

1) Chemical Degradation

2) Thermal Degradation

3) Permeability

A.S.T.M. test standards pertaining to the above topics were reviewed and relevant tests were examined. Due to the very thin cross-section of the extruded Coroplast sheet, direct application of A.S.T.M. tests was precluded. Consequently, this information on test methodology was used as a guide for experimental procedures which were designed specifically for this material and application.

The original research plan included an alternate plastic (Polycarbonate) for consideration as a condensing heat exchanger construction material in the event that Coroplast proved to unacceptable. This plastic sells under the name "Tuffac Twinwall" and costs approximately five times as much as Coroplast. Plans included testing both the Coroplast and the Tuffac for degradation due to chemical or thermal means. The experiments performed were designed to test the plastics for degradation in the application of condensing heat exchanger service. A literature review regarding polycarbonate (Tuffac) and polyethylene/polypropylene (Coroplast) revealed no apparent materials problems (3).

4.2) CHEMICAL DEGRADATION

According to the literature, both Tuffac and Coroplast have excellent resistance to acids. Thus, both of these plastics appear to be well suited for this application. To verify this conclusion, a number of tests were designed and undertaken. These experiments included:

1) Samples immersed in condensate for the contract duration.

2) A continuous condensation test using a pilot flame and a Coroplast heat exchanger.

3) A full scale furnace subjected to long time steady state as well as cyclic operation.

The above chemical degradation tests indicated that both polymers, Coroplast and Tuffac, are adequate for this application as no degradation was evident. The following sections describe the experiments, and outline the results.

4.2.1) Immersion Test

Samples of both Coroplast and Tuffac were immersed in a bath of untreated furnace condensate. The baths were kept at room temperature for the contract duration. Subsequent examination revealed no dimensional changes or surface degradation. The colour of the samples had not changed. The samples were subjected to bending deformation and examined for embrittlement. There were no signs of embrittlement and the samples responded to the test in a manner similar to that of new material.

4.2.2) Pilot Scale Condensation Test

A test apparatus was constructed to subject a 0.82 meter length of Coroplast (three channels wide) to continuous flue gas condensation. This experiment utilized a pilot flame assembly which supplied flue gas to the Coroplast inlet at a temperature slightly higher than the steady state temperatures encountered at the inlet of the Coroplast heat exchanger during prototype furnace operation. See Figure 12. An induced draft blower drew flue gas through the Coroplast channels while a second blower cooled the outside of the Coroplast with room temperature air in a counter flow arrangement. The flue gas from the pilot flame was allowed to enter the Coroplast section at a nominal temperature of 110C and was cooled to near room temperature. This test was continued for seven months. This experiment revealed interesting information regarding the mechanism by which the condensate is cleared from the Coroplast channels.

Condensation occurs evenly on the channel walls and becomes visible as a fine mist which gradually coalesces into larger and larger droplets. These droplets, when of significant size, break free from the wall and flush the entire channel clear. At this time, condensation takes place again as a fine mist. This is a cyclic process which causes the flow restriction of the Coroplast channels to vary in a cyclic manner. As a result, the flow rate through the Coroplast channels of the test apparatus would also vary in a cyclic fashion. This caused the point of initial condensation in the Coroplast channels to fluctuate in position. This motion of the condensate front occurred over a distance of approximately 7 to 8 cm.

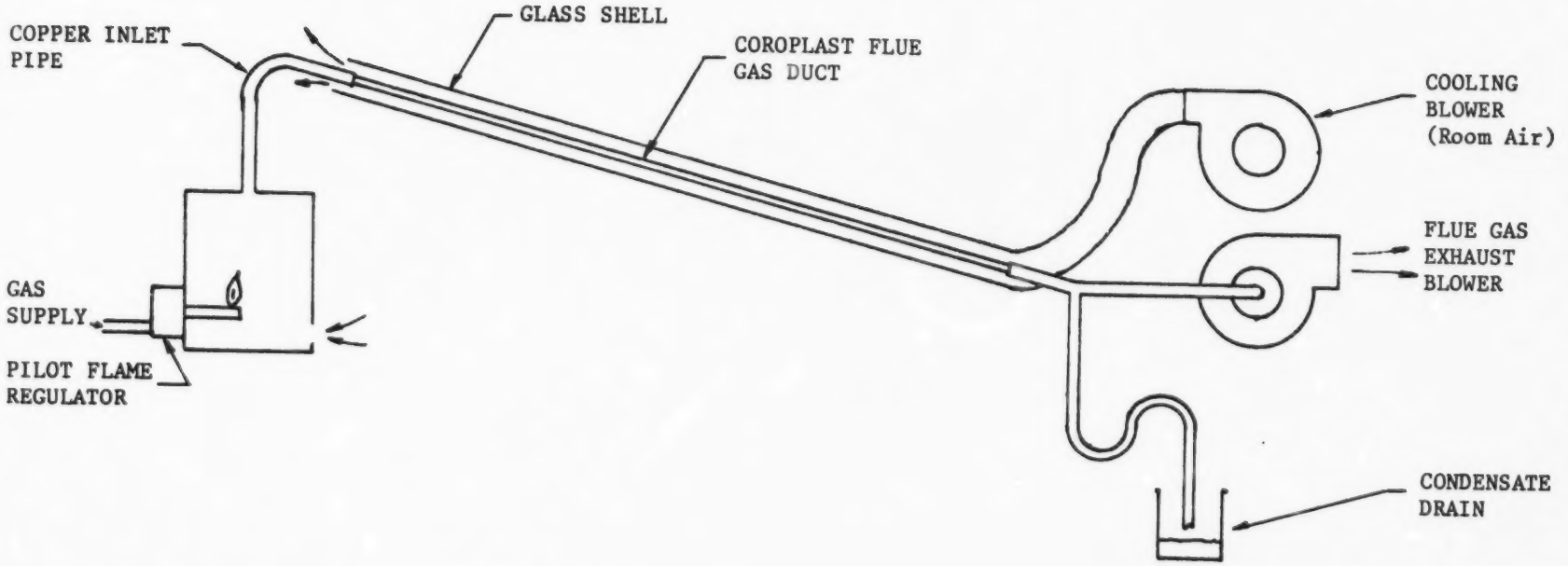


Figure 12: Continuous Condensation Test Apparatus

Thus, the plastic in this region would become wet and dry in a cyclic pattern. This action corresponds well to the leading edge of the condensation front in the furnace Coroplast heat exchanger.

Subsequent examination revealed no dimensional changes or surface degradation. The inlet section was tinted slightly yellow as a consequence of igniting the pilot flame with matches (sulphur). Bending tests were performed and revealed no embrittlement.

4.2.3) Full Scale Condensation Test

The prototype furnace was subjected to cyclic operation for a period of more than 800 cycles for the purpose of materials testing and performance validation. Upon completion of this test, the furnace was inspected and particular attention was given to the Coroplast heat exchanger. There were no signs of chemical degradation present.

4.3) THERMAL DEGRADATION

The flue gas from the furnace enters the Coroplast heat exchanger at approximately 93C. The application of plastic as a heat exchanger material requires investigation for the possibility of thermal degradation. This aspect of plastics performance was evaluated by various experiments including elevated temperature tests, the continuous condensation experiment and in situ furnace performance testing.

4.3.1) Elevated Temperature Test

The elevated temperature test was carried out as follows. Twenty seven samples each of Coroplast and Tuffac were held at three dry temperature levels for various periods of time. Preliminary investigations revealed that Coroplast will soften at temperatures above 130C. Test temperatures chosen were 93C, 110C and 127C in order to cover an adequate range. Nine samples of each plastic were held at each of the three temperature levels. Samples were withdrawn and tested at 1 day, 2 days, 4 days, 1 week, 2 weeks, 1 month, 2 months, 4 months and 6 months.

Subsequent examination of the samples revealed no dimensional change, colour change or embrittlement. During the course of these experiments, it was found that Coroplast samples at the high temperature (127C) would deform slightly if they were in a stressed state. The temperature limit for furnace operation (110C) is expected to prevent such problems. Thermally aged samples were later tested for permeablility.

During the elevated temperature test a mishap occurred which revealed an interesting phenomenon. After four months of

continuous testing, the high temperature oven was inadvertently alterred and its temperature control was set to its maximum setting. Upon subsequent inspection, all of the remaining samples had vanished. It was decided that further investigation was warranted. Elevated temperature tests were carried out using both gas chromatograph and thermal gravimetric test methods. Both tests showed weight loss from a Coroplast sample beginning at approximately 370C. The sample had approximately 95% of its mass driven off by 450C.

4.3.2) Pilot Flame Performance

The pilot flame continuous condensation test, described previously, subjected the Coroplast sample to a nominal flue gas inlet temperature of 110C for a period of six months. This Coroplast was undamaged and was free of signs of thermal degradation such as embrittlement or crazing.

4.3.3) In-Situ Testing

The Coroplast heat exchanger in use on the prototype furnace was inspected after the cyclic performance test. This examination revealed no irregularities. This furnace was designed in such a way that the flue gas inlet temperature to the Coroplast heat exchanger is low enough to avoid overheating and/or thermal degradation. However, during the testing of earlier development designs a malfunction occurred which resulted in overheating of a Coroplast heat exchanger. This caused slight damage of the flue gas inlet channels. See Figure 13. The resulting distortion in the channel ends resulted in a break in the seal between the silicone caulking and the Coroplast sheet. This resulted in a leak of air into the flue gas recirculation loop. Efforts have been made to overcome this type of problem in subsequent designs through the use of control devices intended to prevent overheating of the Coroplast heat exchanger.

4.4) PERMEABILITY TESTING

Permeability tests were carried out as part of the research into plastics assessment. The experiments consisted of pressurizing one side of a Coroplast sample with helium at one half atmosphere pressure. A pressure sensor, capable of detecting a 0.01 psi pressure change, was used to monitor the pressure in the chamber located on the opposite side of the Coroplast sample. Refer to Figure 14. This test was run using a new Coroplast sample as well as one which had been thermally aged for four months at 110C in dry air. The pressure differential across the samples was maintained for twenty four hours. In both cases there was no evidence of permeation. Since the molecular weight of combustion products is much greater than that of helium, no permeability problems are forseen.

Figure 13: Damaged Coroplast Heat Exchanger

Note broken seal and slightly collapsed ribs.

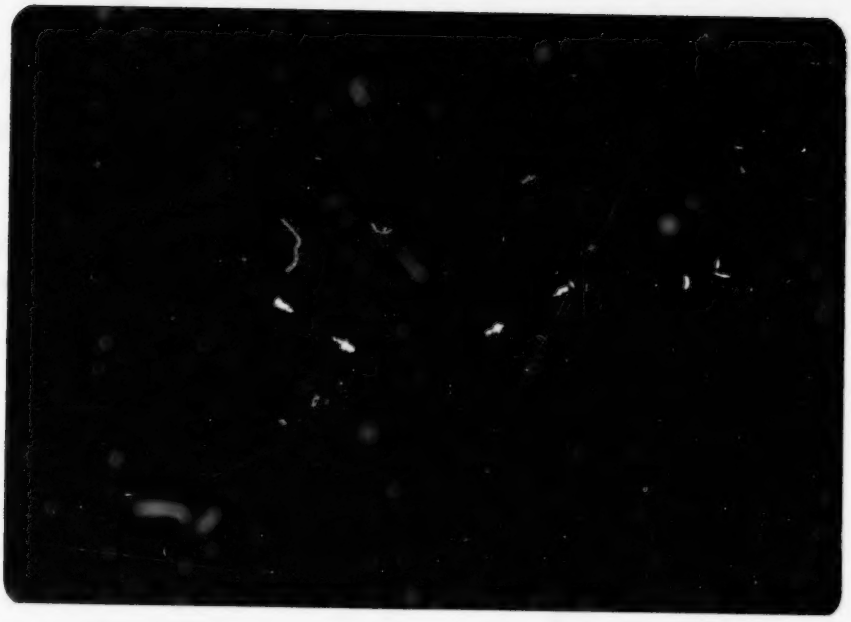


Figure 14: Permeability Test Apparatus

CHAPTER 5

CONDENSING HEAT EXCHANGER CONSTRUCTION

The prototype furnaces contain condensing heat exchangers which are made of Coroplast. The heat exchanger core has overall dimensions of 11.43 cm x 54.61 cm x 50.8 cm. The core is made up of Coroplast sheets which carry flue gas (10.16 cm x 54.61 cm) which are sandwiched alternately with sheets of Coroplast which carry house air (11.43 cm x 53.34 cm). The slight difference in size of these sheets provides a lip which facilitates the installation of inlet and outlet manifolds. The discrepancy in size also provides a groove between alternate sheets of Coroplast on the open flow faces of the heat exchanger. This groove allows the sealing of the heat exchanger on the flue gas inlet and outlet sides.

The installation of inlet and outlet manifolds to the Coroplast heat exchanger requires a leak proof seal of both the Coroplast sheets to one another and of the manifold-Coroplast joint. The joint or seal must withstand the same environment as the Coroplast. The following discussion outlines the problems associated with the design of the seal.

There are two basic techniques for sealing or joining plastics. These are adhesives, or one of several types of plastic welding processes. In an effort to find an applicable welding process, three firms which specialize in differing techniques of plastics bonding(4) were contacted. These firms were also presented with Coroplast samples. Due to the exceptionally thin cross section of the Coroplast wall, no affirmative replies were received. Thus, the choice of sealants was narrowed to the use of adhesives.

The adhesives used to seal the Coroplast heat exchanger were Dow Corning silicon and Bostik hot glue. The flue gas inlet end of the Coroplast was sealed using silicon caulking which is capable of withstanding temperatures to 172C and has good resistance to chemical degradation (5). Bostik hot glue was selected to seal the outlet end of the heat exchanger due to its lower cost and ease of application. Hot glue has good resistance to chemical degradation (Its composition is assumed to be similar to that of Coroplast.) but softens at temperatures in excess of 83C. This softening temperature imposes no limitations, as the flue gas exits the heat exchanger at a nominal temperature of 37C.

The adhesives used to seal the Coroplast heat exchanger were applied by hand. The technique which evolved required great care and patience to ensure a leakproof seal. One of the problems encountered in sealing the heat exchangers stems from the manufacturing tolerences characteristic of the

Coroplast sheet. The dividing ribs are not perfectly straight, parallel or equally spaced. Hence, when the sheets were cut to size to make up heat exchanger blanks, a rib would be sheared occasionally. If that channel were not sealed at both ends, a leak would occur at the sheared rib. Therefore, the sealing of the Coroplast heat exchanger and manifolds required meticulous care and testing.

The economical manufacture of Coroplast heat exchangers would require an alternate technique to that used to seal the heat exchangers of the prototype furnaces. Various alternate designs might be envisaged, but the difficulties associated with the poor manufacturing tolerences of the extruded Coroplast sheet cannot readily be overcome. The challenge of economical manufacture of the Coroplast heat exchangers requires further research and development.

CHAPTER 6

FURNACE COMPONENT RELIABLILITY

The assessment of furnace components requires examination of both materials performance and component operational reliability. Many of the parts used in the construction of the prototype furnace are identical to those in use in standard residential gas furnaces. Since the service requirements are similar, these components are expected to be highly reliable. These parts include the main blower assembly, primary heat exchanger, ignition system, regulator, and burner assembly. The following discussion is limited to those components which are not used in conventional residential gas furnaces or which are used for non-conventional applications.

The furnace components of immediate concern are the condensing heat exchanger, associated ductwork and blowers, control devices, and the condensate treatment system. Many of these components are being used in similar service, on high efficiency, gas fired, furnaces, with no apparent difficulty.

Flue gas exits the primary heat exchanger at approximately 330C and enters the recirculation duct. This flue gas is tempered by the flow of cool flue gas from the recirculation blower. The mixed and tempered gases enter the Coroplast heat exchanger at approximately 93C. The ductwork connecting the primary heat exchanger to the condensing heat exchanger is fabricated from zinc coated sheet metal. The joints of this duct are all sealed with silicon sealant or fiberglass insulation. As the temperature of the mixed flue gases is above the dew point temperature, no corrosion problems are expected at this location. The inlet manifold of the Coroplast heat exchanger is constructed in a similar manner and is also expected to be free of problems. No evidence of any corrosion has been detected in any of this ductwork as a result of the furnace operation which has been carried out to date.

The cooled gases leave the Coroplast heat exchanger at approximately 37C. The flow consists of saturated flue gas and condensate. The outlet manifold is fabricated from zinc plated steel, and has been coated on the flue gas side with coal tar epoxy. This coating exhibits excellent corrosion resistance. See Appendix 1 for further specifications.

Both the exhaust and recirculation blowers draw the flue gas from the outlet manifold via flexible fiberglass ducts. The blowers both have plastic coated casings and blower wheels. This model blower has been used in a similar environment by Clare Brothers Ltd. in their Megasave condensing furnace. No corrosion or reliability problems are anticipated in the

present application. The condensate treatment package used on the prototype furnace is also identical to the unit in use on the Clare Brothers Ltd. condensing furnace and is thus well suited for this application. All of these flue gas handling components located on the wet end of the furnace are protected against corrosion and no difficulties are expected.

The control system components which could possibly be damaged as a result of corrosion are the sail switch (PN 21), the temperature control (PN 9) and the pressure switches (PN 11, PN 12). Refer to Figures 3,4 and 5. The pressure switches are identical to those in use on the Clare Brothers Ltd. Megasave furnace and are expected to be free of problems. The sail switch is installed at the exit of the recirculation blower with the sail and support arm in the flow. As the flue gas is saturated in this location, the possibility of condensation will be examined. The flag or sail consists of a rectangular piece of sheet metal attached to a support arm. Since the cross section of the support arm is very small, the resistance to heat transfer from the sail to the environment will be quite large and the surface of the sail may be considered to be adiabatic. Thus, little or no condensation will occur on the surface of the sail before it reachs equilibrium with the recirculated flue gas. The temperature control located in the recirculation duct upstream of the Coroplast heat exchanger (PN 9) is in a position where the temperature of the flue gas is above the dew point temperature. Neither corrosion of the sail switch nor of the recirculation duct temperature control has been noted to date. It is expected that these components will continue to be free of corrosion. However, annual inspection of these furnace controls is recommended.

CHAPTER 7

PERFORMANCE VALIDATION

7.1) APPROACH

A large portion of the research involved in prototype furnace production was devoted to performance and reliability validation. This work was necessary for the iterative fault determination and design revision process which led to the finalized prototype design. The refined prototype furnace was tested for reliability, performance and safety. These tests involved cyclic furnace operation to ensure trouble free service, as well as failure tests in which critical furnace components were disabled in order to ensure that the furnace would not create a safety hazard or damage itself before the control system turns the furnace off.

7.2) COMPONENT FAILURE TESTS

Component failure testing was performed with three objectives:

1) Ensure control system will automatically interrupt burner operation in the event of a component malfunction

2) Ensure that individual component failures will not result in damage to the furnace

3) Ensure that furnace breakdown will not result in a safety hazard

The component failure tests were accomplished by turning off, or creating a malfunction of, critical components while the furnace was operating at steady state. Observations were then made of the time required for burner shut down. The peak temperature reached at the inlet to the Coroplast heat exchanger was noted in each case. The control device which caused the burner interrupt was also noted.

The results of the component failure tests are shown in Table 1. The furnace safety protection devices successfully prevented damage. The main concern in these tests was the safety of residence occupants, and overheating of the Coroplast heat exchanger. During the failure test of the main blower, the temperature at the Coroplast heat exchanger inlet rose to 110C thereby shutting down the furnace (Temperatrue control located at the Coroplast heat exchanger inlet). Had this temperature control failed to shut down the furnace, the temperature control between the primary heat exchanger shells would have interrupted the burner circuit.

Furnace Component	Time required for Burner Shut Down (seconds)	Peak Temperature at Condensing Heat Exchanger Inlet (°C)	Control Device Causing Shut Down
Recirculation Blower	6	no increase	Sail Switch/Low Pressure Switch
Exhaust Blower	2.5	no increase	Low Pressure Switch
Main Blower	38	110	Temperature Control at Condensing Heat Exchanger Inlet
Exhaust Blower Inlet Hose Break	1	no increase	High Pressure Switch
Recirculation Blower Inlet Hose Break	10	no increase	Spill Switch

TABLE 1: Component Failure Tests

7.3) CYCLIC TESTING

In order to assess the prototype furnace reliability in actual use, the furnace was put through a cyclic operation test. This test was accomplished by using a timer circuit to request heat for a five minute interval and then shut down for a period of five minutes in cyclic operation. This test continued over a period of several months and cycled the prototype furnace through more than 800 complete cycles. The furnace was under observation for the duration of the test, and a close inspection of the furnace components was made upon completion of the test. The advantage of such an experiment is apparent. The furnace is subjected to the rigours of operation including thermal fatique (since the temperature levels swing from minimum to maximum), cyclic condensation and cyclic control operation.

The protǫtype furnace was partially dissassembled upon completion of the cyclic testing. Inspection was made of all components. No evidence of corrosion, thermal degradation or malfunction was found. The control system functioned reliably throughout the test. On the basis of this test, the prototype furnace design is expected to be both reliable and free from degradation as a result of cyclic operation.

CONCLUSIONS

The prototype furnaces produced during this project have a steady state efficiency of approximately 92%. The thermal performance of these furnaces is in good agreement with predicted results. This furnace design shows potential for further development.

Both Tuffac and Coroplast plastics appear to be well suited for use as a heat exchanger material in this application. These plastics were tested for chemical and thermal degradation. Coroplast was tested for permeabliity. There was no evidence of plastic degradation in any of the plastics testing or as a result of furnace operation.

The thermal performance of the Coroplast heat exchanger with respect to heat transfer is quite good.

The prototype furnace has been tested in both steady state and cyclic operation. The safety system has been checked and the control system tested. There are no problems anticipated with respect to furnace reliability or safety.

The recirculation loop, as designed, is capable of cooling the flue gas to below 95C. This design may find application in a variety of furnace configurations and merits further research.

RECOMMENDATIONS

The prototype furnaces constructed during this project have been tested and show potential for practical application. There are two areas which require additional research; the economical manufacture of leak free Coroplast heat exchangers, and the improvement of the recirculation/exhaust blower flue gas handling system.

It is recommended that an investigation be made of the cost effective manufacture of Coroplast heat exchangers. The main concern is the prevention of leakage. Hence, information regarding alternative sealing techniques would be of vital interest. Since the poor manufacturing tolerence of Coroplast creates difficulty in heat exchanger sealing, further research should also approach the use of alternate plastic meterials in this application.

It is recommended that research be conducted into improving the exhaust/recirculation blower system. The current design could be improved by placing both the exhaust and recirculation blower wheels on the same shaft, driving this unit with a common motor. With both blower wheels operating at the same speed, the balance between recirculation and exhaust flows could be tuned by means of design adjustment of the two blower wheels. It is expected that this single motor design would reduce the furnace operating temperature sensitivity with respect to exhaust back pressure. In addition, the operation of both blowers on a single shaft would allow some simplification of the furnace control system. The sail switch which is used in the current prototype design to prove recirculation blower operation would no longer be necessary. A failure of the recirculation blower could not occur without a corresponding failure of the exhaust blower which in turn would prevent furnace operation.

REFERENCES

1) Wright, J.L., Sullivan, H.F., "Conceptual Designs of High Efficiency Gas Furnaces", Spider Engineering Associates (Waterloo) Inc., November, 1981.

2) Wright, J.L., Sullivan, H.F., proposal, "Prototype High Efficiency Furnace Development", Spider Engineering Associates (Waterloo) Inc, September, 1981.

3) Houston, J.S., "Polypropylene", Modern Plastics Encyclopedia, 1976-77.

Dirshenbaum, G.S., "Polypropylene", Modern Plastics Encyclopedia, 1976-77.

Hadden, C., Belmont, C., Bullet, R., "Polycarbonate" Modern Plastics Encyclopedia, 1976-77.

4) Written communications from:

Dukane Corporation
2900 Dukane Dr.
St. Charles, Ill.

KamWeld Products Co.
Box 91
Norwood, Mass.

Plastisonics Equipment Ltd.
431 Nugget Ave.
Scarborough, Ontario

5) Dow Corning Silicon
Dow Corning Canada, Inc.
6747 Campobello Rd.
Mississauga, Ontario

APPENDIX 1

SPECIFICATIONS OF COAL TAR EPOXY COATING

Amercoat® 78

Amine-cured coal-tar epoxy

Ameron

A tough, corrosion and abrasion resistant amine-cured coal-tar epoxy

An excellent coating for marine structures, industrial use, and tank lining immersions

Excellent water and chemical resistance

16 mils in only two coats: no primer or topcoat needed

Typical Uses

Marine structures, ship bottoms, bilges, and cargo ballast tanks. Industrial coating in power plants, oil refining, and sewage treatment plants. Lining for intermittent or continuous immersion in alkalies, crude oil, salt solutions, and fresh or seawater.

Conforms to U.S. Navy Specification MIL-P-23236 (Ships) Type 1, Class 2, Coal-Tar Epoxy. Also acceptable for the same uses on U.S. Coast Guard vessels.

Outstanding Characteristics

Amercoat 78 is a high-performance chemical- and corrosion-resistant amine-cured coal-tar epoxy.

This high film build coating provides protection against fresh and seawater as well as a wide variety of chemical atmospheres. Suitable for use over both steel and concrete.

Systems Using Amercoat 78

Amercoat 78 normally does not require a primer or any additional topcoats. In the event that a holding primer is required, Amercoat 71 Primer may be used. Dimetcote® can be used as a primer for Amercoat 78 when the cathodic protection provided by an inorganic zinc is required. For immersion service, Amercoat 71 is recommended as a tiecoat between Dimetcote and Amercoat 78.

Amercoat 78E is available (in black only) to comply with South Coast Air Quality Management District Rule 442 (formerly Rule 66) and equivalent regulations applicable to surface applied coatings and solvents. The "E" version has a flash point lower than specified in MIL-P-23236, but the dried coating conforms in all respects. Order Amercoat 10E thinner and Amercoat 12E cleaner.

Chemical Resistance Chart

Environment	Suitability of Amercoat 78 Splash and Spillage
Acidic	Excellent
Alkaline	Excellent
Salts	Excellent
Solvents	Excellent
Petroleum products (crude)	Excellent
Petroleum products (clean)	Not recommended
Fresh and saltwater	Excellent

This chart is only a guide to show typical resistance of Amercoat 78. Your Ameron representative will help you evaluate your particular corrosion protection needs and make the correct recommendation for your specific requirements.

Physical Data

Finish	**Flat**
Color	**Black and red**
Applied over	**Steel or concrete**
Components	**2**
Cure	**Solvent release and chemical reaction between components**
Volume solids	**Black, 72%, red, 69%**
Dry film thickness	**8 mils (200 μ) per coat**
Coats	**1 or 2**
Calculated coverage at 8 mils (200 μ)	**Black, 144 sq ft/gal (3.5 sq m/ltr) Red, 138 sq ft/gal (3.4 sq m/ltr)**

Allow for application losses and surface irregularities.

Application	**Conventional or airless spray**
Pot life	**4 hrs @ 70°F (21°C)**
Drying time @ 77°F	
Dry to touch	**6.5 hrs**
Dry hard	**11.5 hrs**
Dry through	**15.5 hrs**

Pot life, drying and curing times are dependent on temperature. Environmental conditions are especially critical for this class of coating. See Application Instructions.

Mixing ratio (by volume)	**1 part hardener to 19 parts resin**
Temperature resistance	
Dry	**300°F (150°C)**
In neutral salt solutions	**160°F (71°C)**
In fresh water	**140°F (60°C)**
Flash point (ASTM D-93)	**P-M closed cup**
Amercoat 78	**113°F (45°C)**
Amercoat 78E	**61°F (16°C)**
Thinner	**Amercoat 10**

Use Amercoat 7 when high flash point is required (e.g. to conform to MIL-P-23236).

Cleaner	**Amercoat 12**
Packaging	
Resin solution	**4.75 gals in 5-gal pail**
Hardener	**0.25 gal in 1-qt can**
Shipping weight 5-gal unit	**63.5 lbs (28.8 kg)**
Shelf life	**1 year from shipment date when stored indoors**

Amercoat® 78

Application Data Summary

For complete information on procedures, environmental requirements, equipment, and safety precautions, see Amercoat 78 Application Instructions. Like all high-performance coatings, Amercoat 78 must be applied as recommended to obtain the maximum protection for which this coating is formulated.

Surface preparation—Steel: abrasive blast. Concrete: abrasive blast or acid etch.

Equipment—Standard industrial spray equipment, conventional or airless.

Film thickness—To obtain the optimum corrosion protection and chemical resistance of Amercoat 78, the recommended dry film thickness is normally 16 mils (400 microns) applied in two coats. For less severe weather and chemical exposures, however, only one coat at 8 mils (200 microns) is adequate. Consult Ameron for specific types of service where the lower thickness may be used.

Drying and curing times

—Dry to touch @	90°F –	3.5 hrs
	77°F –	6.5 hrs
	50°F –	12.5 hrs
—Dry hard @	90°F –	7.5 hrs
	77°F –	11.5 hrs
	50°F –	30.0 hrs
—Dry through @	90°F –	10.0 hrs
	77°F –	15.5 hrs
	50°F –	48.0 hrs

Safety—Since improper use and handling of Amercoat 78 can be hazardous to health and cause fire or explosion, safety precautions included with the Application Instructions should be strictly followed during all storage, handling, use, and drying periods.

Warranty

Ameron's products are warranted to be free of defects in material and workmanship. If a product does not conform with this Warranty, Buyer must notify Ameron within five days of discovery of the defect, but in no event later than one year after delivery date or after expiration of the applicable shelf life, whichever is shorter. Ameron's sole obligation under this Warranty shall be at its option, to credit Buyer's account, or to supply replacement material or repair. Failure to notify Ameron of nonconforming goods under this Warranty, within the time specified above, shall bar Buyer from recovery hereunder.

It is expressly understood that Ameron makes no other warranties concerning the goods, and the sole remedy of the Buyer and the sole liability of Ameron for product defect shall be as set forth above. No other warranties, express or implied, whether of merchantability or of fitness for any particular use shall apply. Ameron shall not be responsible for consequential damages.

Any recommendation or suggestion relating to the use of the products made by Ameron either in technical literature or in response to specific inquiry is given in good faith, but it is for Buyer to satisfy itself of the suitability of the goods for its own particular purpose and it will be deemed to have done so.

201 North Berry Street
Brea, California 92621

Trelerweg 7
4191 NE Geldermalsen, The Netherlands

Ameron®

Protective Coatings
Division

APPENDIX 2

RECIRCULATION FURNACE INSTALLATION INSTRUCTIONS

INSTALLATION INSTRUCTIONS

1) Connect ductwork (including filter rack and filter)

2) Connect electricity (115 VAC, 15 Amp Slo-Blo fuse)

3) Operate air blower. Pressure rise through furnace should not exceed 0.25" w.c. If the air pressure rise through the furnace is less than 0.2" w.c., the current draw of the air blower motor should be measured. This current can be reduced, if necessary, by reducing the speed of the air blower.

4) Connect exhaust tubing.

5) Connect right hand hose at the rear of the furnace to a suitable condensate drain.

6) Connect and turn up thermostat allowing furnace to operate*.

7) Monitor excess air level† after furnace ignition and as furnace warms up.

8) Adjust exhaust tube back pressure (using a butterfly valve or tape applied to the outlet opening) such that the furnace operates at 35% excess air at steady state.

9) Switch off furnace and allow to cool for 30 minutes.

10) Shut off gas supply and switch on furnace.

11) Measure the back pressure of the exhaust tubing during exhaust blower operation. This pressure measurement can be made at the clear tubing which is connected to the pressure switches in the right side of the front cabinet.

12) Remove the butterfly valve or tape from the exhaust tubing and install a suitable orifice which provides the same amount of back pressure.

13) Operate the furnace and remeasure the amount of excess air. Adjust the exhaust orifice as required.

* If the electronic ignition does not activate within 1 minute of exhaust blower operation, it is probable that too much or too little exhaust tube has been installed and that the ignition is being held open by either the high pressure switch or the low pressure switch, respectively.

† A ¼" hole is provided on top of the primary heat exchanger outlet to monitor excess air, temperature, etc. This hole is blocked with a bolt when not in use.

POOR

QUALITY

ORIGINAL